REPORT NO. T 6/82

A MICRO-COMPUTER BASED SYSTEM FOR HIGH PRECISION TEMPERATURE MEASUREMENT USING PLATINUM RTD'S

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
Natick, Massachusetts

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A micro-computer controlled system for 10 channel high precision temperature data acquisition has been developed. The temperature sensing elements are Platinum Resistance Thermometer Devices (RTD's). Probe construction, using standard, commercially available RTD elements is described and wiring and switching requirements for the 4-wire resistance measurements are noted. The system consists of a Digital Equipment Corp. MINC-11 Computer linked, via IEEE-488 interface bus cables, to a HP (Hewlett-Packard) 34555A Digital Volt/ Ohm Meter, an HP-3495A Scanner/Multiplexer, and, during calibration, a HP 2804A

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Quartz Thermometer. Two programs are employed: one for probe calibration and the other for the temperature measurement application. In the calibration program, the ten probes are individually calibrated against the Quartz Thermometer which has an absolute accuracy specification of ±0.04°C. A proportional control water bath having a thermal stability specification of ±0.004°C provides the common thermal medium during calibration. Currently a three point calibration spanning 6°C (37 to 43°C) is employed. The individual probe constants are computed and recorded on a computer file for access via the temperature measurement program. An initial evaluation of the precision of the calibrated RTD system against the Quartz Thermometer reading yielded an overall precision of ±0.004°C and worst case error of less than ±0.01°C.

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Technical Report

No. T6/82

A Micro-Computer Based System for High Precision Temperature Measurement Using Platinum RTD's

by

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US Army Research Institute of Environmental Medicine,
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ABSTRACT

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INTRODUCTION

Current projects in this laboratory have led to a need for a system capable of making reliable, high accuracy body temperature measurements on small animals under various experimental conditions. During the course of a typical experiment, individual temperature measurements on up to ten animals must be made at one minute intervals over an 8 hour time period. In addition, the system must display these temperatures and other calculated data immediately and record the information thus generated in a form suitable for further computerized processing at a later time.

The overriding consideration in selection of the method and instrumentation was the accuracy/precision of the temperature measurement. The system described here is an attempt to optimize, within practical limits, three crucial determinants of overall accuracy: 1) the precision of the thermal transducer, wiring, and switching 2) the precision of the signal measuring devices and 3) the accuracy of the calibration.

SYSTEM DESCRIPTION

This report describes a micro-computer based temperature measurement system which was developed to meet our requirements using Platinum Resistance Thermometer Devices. Overall system configuration during calibration is shown in Figure 1.

The Sensor: Recent developments in miniaturization have made the platinum resistance thermometer device, or platinum RTD, a very attractive alternative to other electrical temperature sensors such as thermistors or thermocouples. The RTD element changes its resistance with changes in temperature as does a thermistor. Unlike a thermistor, however, this change is

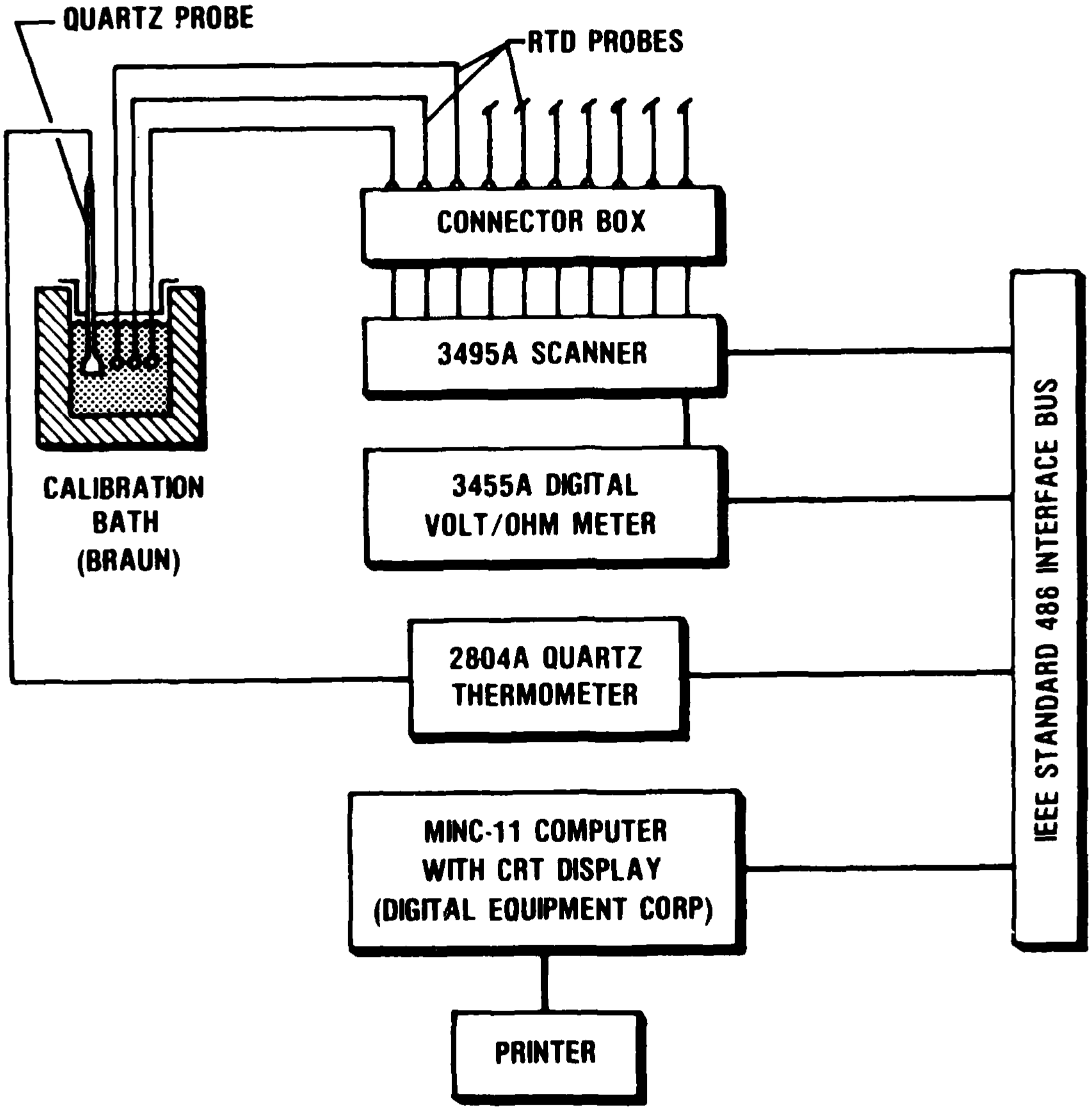

FIGURE 1: SYSTEM CONFIGURATION

linear with temperature. Thus, use of the RTD eliminates the need for either resistor networks to linearize the signal or complex mathematical functions to convert to temperature units. The need for a reference compensation system, required when using thermocouples and itself a potential source of measurement error is eliminated.

The RTD elements chosen for use in this system were obtained from Omega Engineering Inc., Stamford, CT (CAT # W2103). These thin film type elements are ceramic coated and cylindrical in shape (2 mm dia by 7 mm long) with two short platinum leads protruding from one end. They have a nominal resistance of 100 ohms at $0^{o}C$ and a temperature change coefficient of approximately 0.385 ohms/^{o}C.

In order to maximize the precision of the RTD resistance measurement a 4-wire method is used. This requires that 4 wires, 2 wires for each lead on the RTD element, be attached to the RTD and carried, ultimately, through all connections and switches into the signal measuring device.

Probe Construction: The construction of the individual temperature measurement probes, incorporating the RTD's, is shown in Figure 2 and described below.

A 1.5 meter length of 4-wire shiedled cable (MICROTECH, Inc., Bootwyn, PA, CAT # MS-4) serves as the probe body as well as connecting cable. This cable has an outside dia. of 0.106 inches and the individual conductors are 30 AWG, Teflon^{R} insulated. Attachment of the RTD to one end of this cable and a 4 pin connector to the other is accomplished in the following manner:

A 1.5 cm "sleeve" of polyethylene tubing (PE 320, Clay-Adams Inc.) is placed over one end of the cable and pushed up past where the soldered connections to the RTD are to be made. The two pairs of cable conductors are then soldered to the RTD leads. This junction should not exceed 4 mm total

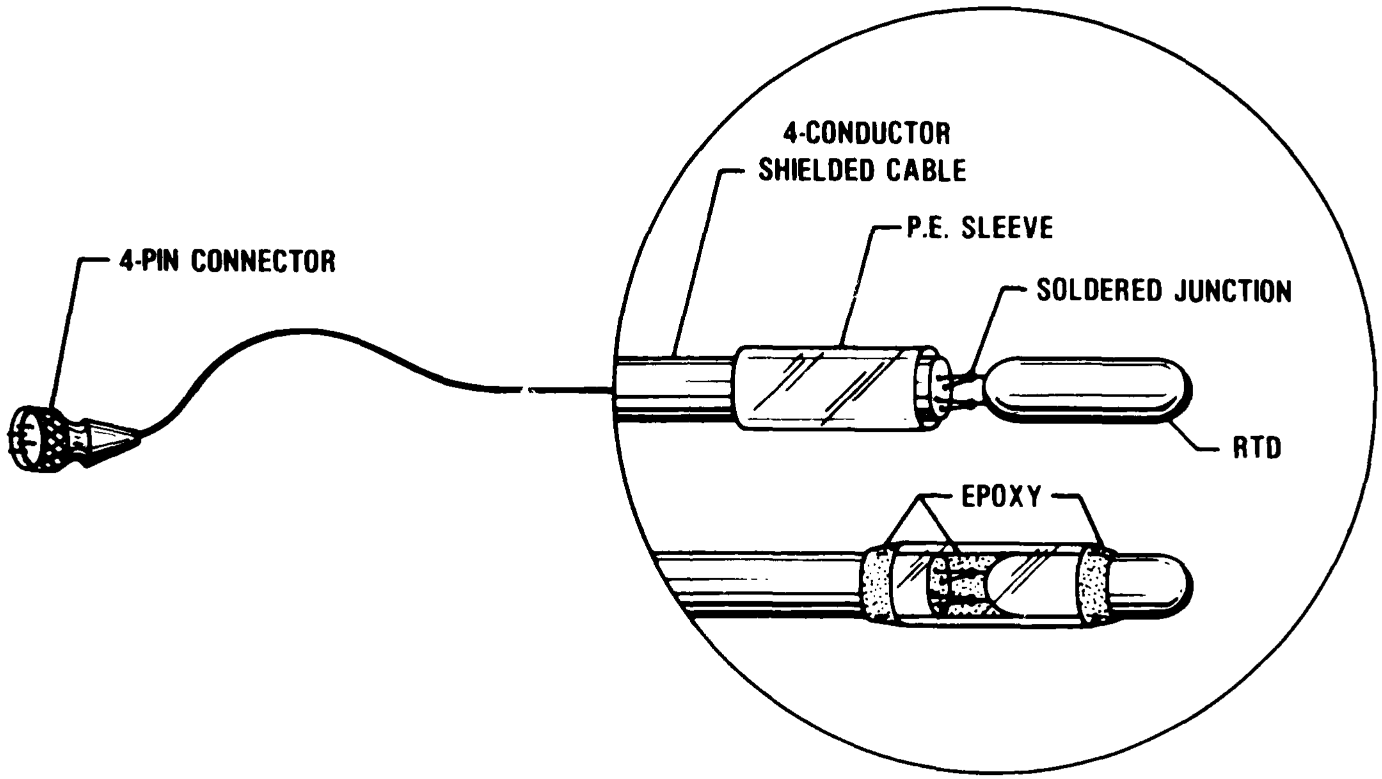

FIGURE 2: PROBE CONSTRUCTION

length for stripped cable, RTD lead, and solder joints. To insure that the two conductor pairs remain isolated from each other in this junction, a small plastic spacer should be glued into place between them. The junction is then thoroughly coated with epoxy and the sleeve pushed down over the junction and halfway down the length of the RTD element. The excess epoxy is removed leaving a small amount on the cable and RTD ends of the sleeve to smooth the transition to its slightly larger diameter. After drying, a mechanically solid and waterproof electrical junction has been accomplished. A micro-miniature 4 pin plug (MICROTECH, Inc., Bootwyn, PA, CAT # DP-4S-1) is attached to the other end according to the manufacturers instructions.

Wiring: Wiring and switching of the individual probes into the signal measuring device are shown in Figure 3 and described below.

A connector box consisting of 10 microminiature panel mounted 4 pin jacks (MICROTECH, Inc, Bootwyn, PA CAT #DR-4S-6) permits rapid connect/disconnect of the individual probes from the system. The jacks are wired directly to the switching/multiplexing device. Two 20 conductor (22 AWG) color coded ribbons are a convenient way to accomplish this connection.

Scanner: The switching device is a Hewlett Packard model 3495A programmable scanner/multiplexer. This device is operated under computer control thru the IEEE standard 488 Interface Bus. Since only two wires (and ground) are normally switched with each channel, two channels must be committed for the switching of all four wires on each probe: 20 channels for 10 probes. The simultaneous closure of two channels at a time, thus connecting all 4 wires of a given probe to the measuring device, is easily programmed into the 3495A. Only 4 wires connect the 3495A scanner/multiplexer to the signal measuring device.

Resistance Measurement: The signal measuring device is a Hewlett Packard model 3455A Digital Voltmenter. This device is also operated under

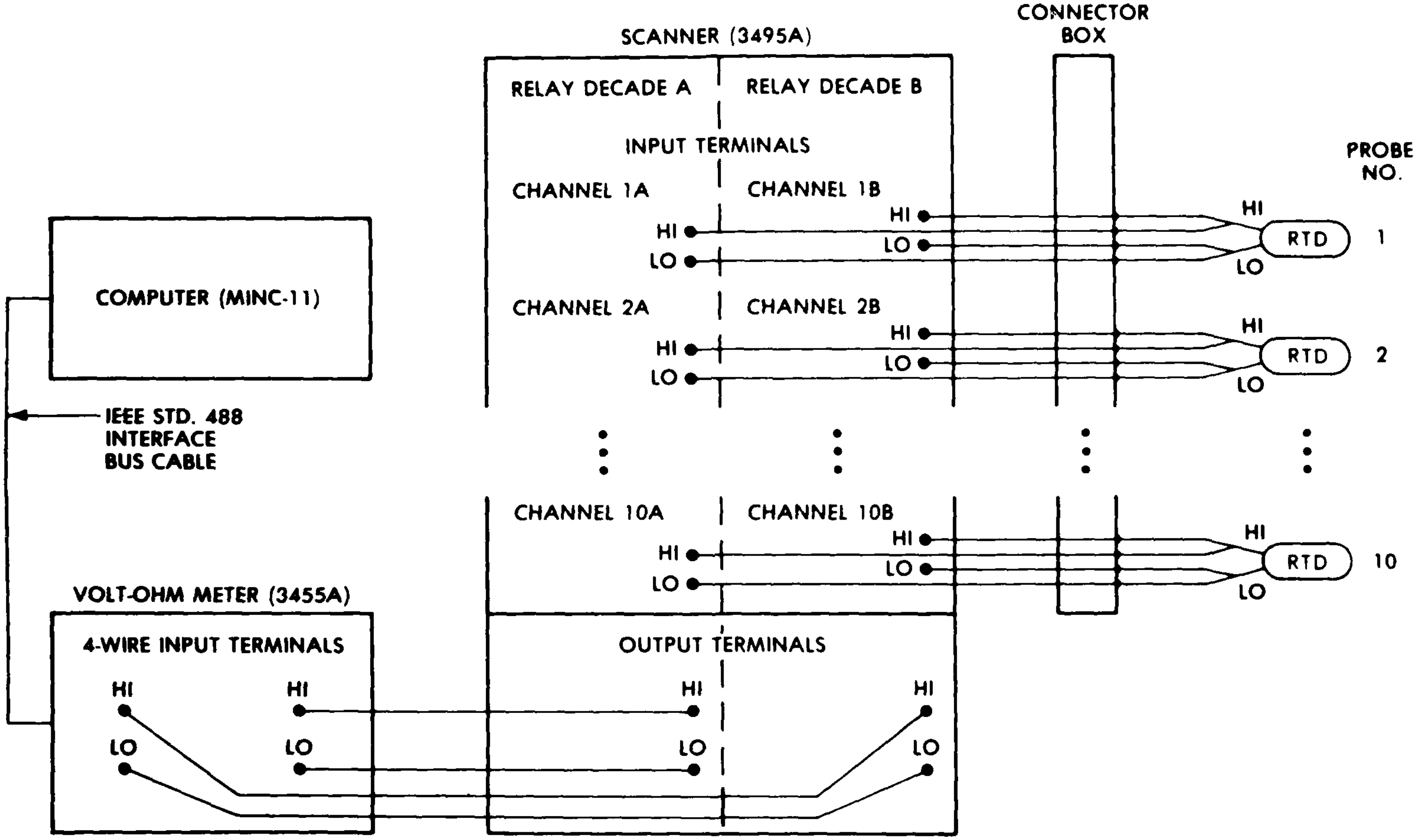

FIGURE 3: WIRING

computer control through the IEEE standard 488 Interface Bus. The 3455A has the capability of making high accuracy 4 wire ohm measurements and transmitting this data over the bus to the computer.

Calibration: Assuming that the probes, wiring, switching, and signal measuring devices have been optimized, calibration of the probes against a reliable temperature standard remains as the final determinant of overall system accuracy.

Certain decisions and assumptions were made at the outset in terms of an approach to the calibration process:

1. The probes are considered to have a linear resistance response to a change in temperature over the range of interest, i.e., the relationship between temperature and resistance may be expressed as an equation of the form $y = mx + b$ where the constants m and b are determined in the calibration process.
2. The probes may be expected to have small but finite differences in these constants due to manufacturing tolerances. Therefore, probes are calibrated individually.
3. The probes are calibrated over a fairly narrow temperature range ($6^{o}C$), in order to minimize the effects of deviation of the probe response from absolute linearity.
4. The probes are calibrated against an electronic temperature measuring device of high NBS traceable accuracy compatible with a semi-automated calibration procedure. An electronic Quartz Thermometer is used for this purpose.

Quartz Thermometer: The Hewlett Packard model 2804A Quartz Thermometer with model 18111A probe is used in this system. This device is operated under computer control through the IEEE std. 488 Interface Bus. It has an absolute accuracy specification of $\pm 0.040^{\circ}C$ from -50 to $+150^{\circ}C$, NBS traceable to IPTS-68. It has a maximum resolution of $0.0001^{\circ}C$.

Calibration Bath: Probes are calibrated in a water bath, the exact temperature of which is measured by the Quartz Thermometer. A major consideration in incorporating the Quartz Thermometer into the calibration procedure is the great difference between the thermal mass of the quartz probe (equivalent to 4.5g water) and the individual RTD probes (equivalent to 0.2g water). This situation may be expected to result in a vast disparity in the response time of these two sensors. Clearly, if both sensors have been given sufficient time to equilibrate with an absolutely stable common thermal medium, the question of response time is unimportant. If however, the medium is fluctuating about a set point several tenths of a $^{\circ}C$, as is common with many water baths, the temperature of both sensors may not be the same at the time the devices are read. Under these circumstances the thermal stability of the *calibrating medium is crucial to the reliability of the calibration.* A Braun model 1480E constant temperature circulator with 6 liter stainless steel bath was selected for the calibrating water bath. This device has a proportional heating control and a stability specification of $\pm 0.004^{\circ}C$. Water in the bath is circulated at 13 liters per minute. A steel cover plate with rubber grommets was designed to hold the probes in place during calibation. The tips are immersed in the bath to a depth of 6.5 cm, the quartz probe is also immersed in the bath, though another hole in the cover to a depth of 8 cm

Calibration Procedure: In general terms, the calibration procedure consists of placing the RTD probes in the calibration water bath along with the Quartz Thermometer probe and recording, via computer, the output of the Quartz Thermometer (temperature in $^{\circ}C$) and each of the 10 RTD probes (Resistance in ohms) at three different bath temperatures. In this way, a thermal standard curve is generated for each probe. At the end of the calibration procedure the two constants, for converting resistance to ^{o}C, are calculated for each probe and stored in a computer file for use during the operation of the RTD temperature measurement program.

A BASIC language program is used for calibration in the present system. The following features of this program should be noted. 1) At three points the calibration program stops to allow time for bath temperature changes. These are set manually and stabilization of the bath temperature must be established by reading the Quartz Thermometer display. The program is resumed by the operator when the conditions are met. 2) The program calls for 10 readings of each probe and the Quartz Thermometer at 37^{o}, 40^{o}, and $43^{o}C$. Individual readings are taken in sequence, beginning with probe 0 and ending with the Quartz Thermometer, for a total of 10 cycles at each calibration temperature. The average value of the 10 readings for each probe and the average value of the 10 Quartz Thermometer readings at that temperature are used in the subsequent calculations. 3) The slope m (in Ohms/^{o}C) for each probe is calculated using the high and low calibration temperature and probe resistances:

Eq. 1. $m = (R3-R1)/(T3-T1)$

where: R1 = Resistance (Ohms) of probe at low cal. temp.

R3 = Resistance (Ohms) of probe at high cal. temp.

T1 = Low cal temp (^{o}C), measured by Quartz Thermometer

T3 = High cal temp (^{o}C), measured by Quartz Thermometer

and the $0^{o}C$ resistance b (in Ohms) is calculated using the previously calculated slope constant and the mid range probe resistance and calibration temperature:

Eq. 2. $b = R2 - m\,T2$

where: R2 = Resistance (Ohms) of probe at mid cal. temp.

T2 = Mid cal. temp ($0^{o}C$), measured by Quartz Thermometer

thus, conversion of a measured probe resistance (R) to ^{o}C is accomplished using the derived constants for each probe:

Eq. 3 Temperature = $(R-b)/m$

4) The calculated constants are stored on a computer file. This means that the calibration program need not be run before each use of the RTD temperature measurement program. 5) The exact set point of the calibration bath at each of the calibration temperatures is not crucial. As long as the temperature of the bath is stable and uniform at the approximate calibration temperatures, the calibration will be valid.

During calibration, the individual probes and the Quartz Thermometer are read at a rate of approximatley two readings per second. The 100 resistance measurements and 10 Quartz temperature readings required at each cal. level are accomplished in less than one minute. A complete 3 point calibration for ten probes can usually be accomplished in 10 to 15 minutes - the major part of that is the time required for the bath to reach a new set point and stablize. Typical calibration constants for 10 probes are shown below:

PROBE NO.	OHMS/DEGREE	OHMS AT 0 DEGREES
0	0.3864	99.98
1	0.3862	100.23
2	0.3864	100.20
3	0.3854	100.06
4	0.3851	100.25
5	0.3850	100.12
6	0.3853	100.23
7	0.3865	100.18
8	0.3864	100.18
9	0.3860	100.00

Once calibration has been accomplished, the Quartz thermometer and water bath may be removed from the system and the probes used to acquire temperature data.

EVALUATION OF THE PRECISION OF THE SYSTEM

Figure 4 shows the results of an experiment designed to evaluate the precision of the system. This test was carried out by placing the calibrated RTD probes and the Quartz Thermometer probe in the water bath at a given set-point and recording the temperature measured by each probe at one minute intervals over a period of 10 minutes. This procedure was repeated at each of seven different bath setpoints spanning the calibration range. Means $\pm$ 1 standard deviation of the 10 RTD temperature values are plotted with the Quartz Thermometer temperature value at that time. Of the 700 RTD temperature measurements made, none differed by more than 0.009^{o}C from the temperature measured by the Quartz thermometer.

These data provide an indication of precision in terms of parity with the Quatz Thermometer, against which the RTD probes were calibrated. Absolute accuracy of the temperatures measured with the RTD's, nevertheless, depends upon the absolute accuracy of the Quartz Thermometer over the calibration range.

In the practical application of the RTD system to a temperature measurement problem, two other properties affecting accuracy need to be kept in mind.

The first of these is response time of the probe to a change in temperature. This is largely a function of the thermal mass of the probe and the medium surrounding it. The RTD probes used here required 8 seconds to respond fully after immersion in the water bath at 37^{o}. Since our application involves the measurement of relatively slow temperature changes, the problem of response time was considered to be insignificant.

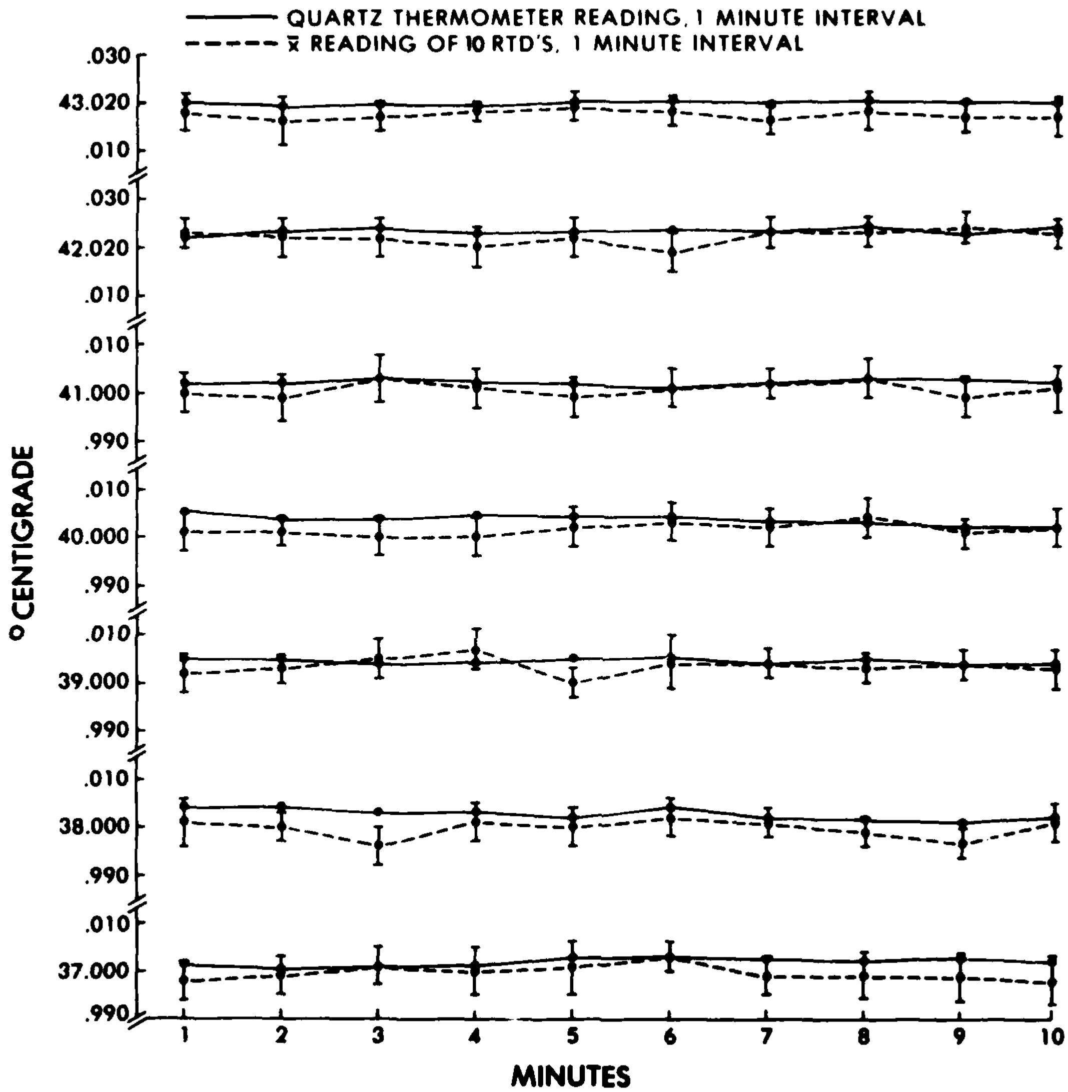

FIGURE 4: RTD'S TRACKING QUARTZ THERMOMETER FOR 10 MINUTES AT 7 BATH SETPOINTS

The second property is self-heat. In order to measure the resistance of the RTD and thus determine its temperature, a small electrical current must be passed through it. When this is done the RTD will have a tendency to heat up, increasing its resistance further. The result is a spuriously high temperature reading. We were unable to demonstrate this effect with our system. There are two likely reasons for this:

First, the RTD's in this system are scanned - the measurement current is applied for only a fraction of a second, thus heating of the RTD element is minimal.

Second, the calibration procedure itself would automatically compensate for any consistent self-heat effects which might be induced during the measurement time.

Increasing the measurement read time or making the measurement in a medium which has a significantly different thermal conductivity than the calibrating medium could reduce overall accuracy of the temperature measurement.

CONCLUSIONS

Platinum RTD's are being used in an increasing variety of commercially available temperature measurement and control devices. Advances in manufacturing processes have resulted in substantial reductions in the physical size of RTD elements. This factor, together with their essentially linear response characteristics and long term stability make these sensors especially desirable for high precision research applications. Within the limitations imposed by the need for 4-wire resistance measurements (i.e. 4-lead wires, multiplexing and meter capabilities) a relatively simple computer based system can be assembled using standard laboratory devices. In terms of accuracy, this system can meet extremely rigorous multi-channel temperature data acquisition requirements.

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